DOT/FAA/CT-89/33

FAA Technical Center
Atlantic City International Airport
N.J. 08405

In-Flight Evaluations of Turbine Fuel Extenders

Augusto M. Ferrara
Carol Rea

February 1990

Final Report

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/CT-89/33		

4. Title and Subtitle

IN-FLIGHT EVALUATIONS OF TURBINE FUEL EXTENDERS

5. Report Date

February 1990

6. Performing Organization Code

7. Author(s)

Augusto M. Ferrara and Carol Rea

8. Performing Organization Report No.

DOT/FAA/CT-89/33

9. Performing Organization Name and Address

Federal Aviation Administration
Technical Center
Atlantic City International Airport, NJ 08405

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

U.S. Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City International Airport, NJ 08405

13. Type of Report and Period Covered

Final Report

14. Sponsoring Agency Code

ACD-210

15. Supplementary Notes

16. Abstract

Flight tests were conducted which evaluated the use of ethanol as a blending agent for turbine fuels. As part of this study, a Beech King Air 200 was modified to incorporate a cabin tank which contained ethanol, and the fuel system was modified to deliver the ethanol to the starboard engine. Ten percent ethanol was mixed with JP-4 in the project fuel line, just before entering the engine. The test was performed over a broad range of operating conditions, and key performance parameters were measured.

The use of ethanol as a blending agent reduced the power available and resulted in an increase in fuel consumption. The increase in fuel consumption was greater than the decrease in energy density. When operating on the ethanol/JP-4 mixtures, the test pilots noted the test engine required more throttle (throttle stagger). No other operational problems were uncovered during the course of the flight tests. A pre- and post-test engine inspection revealed no fuel related damage.

17. Key Words	18. Distribution Statement
Ethanol, Turbine Engines, Alternate Fuels Flight Tests, JP-4	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	37	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

EXECUTIVE SUMMARY

The flight tests, which are described in this report, conclude the Alternate Fuels Program which was conducted at the FAA Technical Center. A Beech King Air 200 was modified to allow the use of 10 percent ethanol in the starboard engine, and the effect of mixing ethanol with the turbine fuel was evaluated over the entire flight envelope.

In general, the use of the ethanol/JP-4 mixtures resulted in less power being developed. Ground based tests also uncovered a similar phenomena, which could be corrected for by advancing the throttle. At altitude there was insufficient throttle authority to increase the power developed. This will result in reduced performance.

The only operational problem noted was throttle stagger while operating the test engine on the ethanol/JP-4 mixtures. This was a consequence of the reduction in power while operating on the test fuel.

The mixture of ethanol and JP-4 has less energy than neat JP-4. The increase in fuel consumption was greater than would be expected based on the energy density calculations alone, indicating the mixture affects the combustion properties of the fuel.

No problems with ethanol solubility or phase separation were noted at fuel temperatures as low as -9.7 °C (14.5 °F).

The test engine was inspected prior to and immediately following the test program. No unusual damage or wear was uncovered which might be related to the use of the test fuel. It should be noted that the test program was of short duration, so these results are inconclusive.

INTRODUCTION

Most turbine equipped aircraft are designed to operate on aviation kerosenes. Since these fuels are petroleum distillates, they represent a finite resource, and there has been some interest in using renewable resources as replacements for aviation turbine fuels. Most of these renewable resources have unfavorable energy densities (energy content per unit weight); therefore, the use of these fuels would adversely affect the payload or range of the aircraft. In addition, the engines would require some redesign to operate on these fuels. As an alternative, it has been suggested that a renewable resources be mixed with an aviation turbine fuel and the resulting mixture burned in the aircraft. The principal proponents of renewable resources have suggested the use of ethanol as the blending agent.

PURPOSE.

The flight tests described in this report were used to evaluate the use of ethanol as a blending agent for aviation turbine fuels with the intention of identifying the operating conditions which might be critical to flight safety.

BACKGROUND.

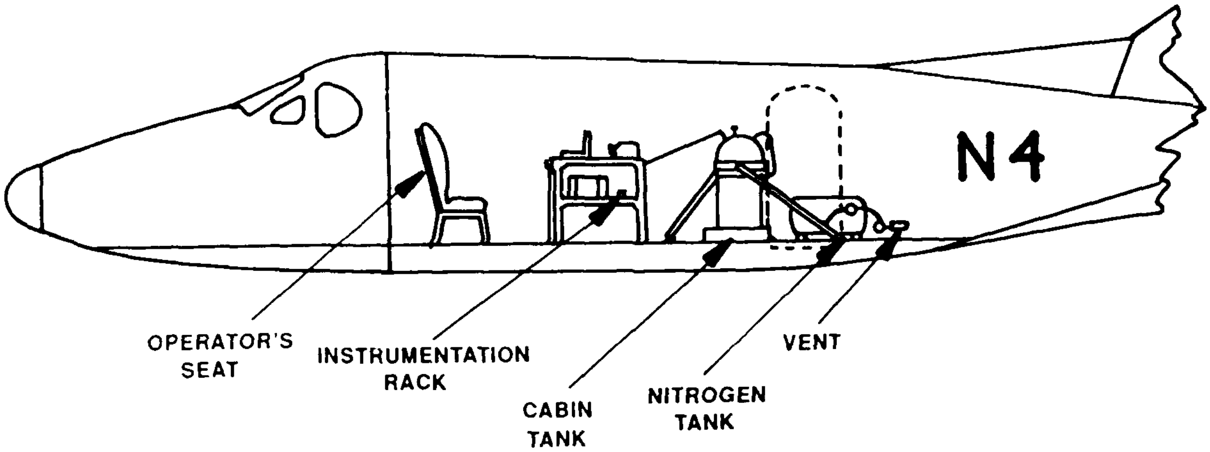
Based on previous studies (references 1,2, and 3), phase separation was identified as a potentially insurmountable problem when blending ethanol with an aviation kerosene. By using a dual fuel system, where the ethanol and aviation kerosene are stored in separate tanks aboard the aircraft and mixed immediately before entering the engine, this problem could be minimized. References 3 and 4 both indicate that the use of more than 15 percent ethanol could result in operational problems without redesigning the fuel control units/nozzles on existing turbine engines. With this in mind, a Beech King Air 200 was modified by adding an ethanol tank, and the aircraft was operated on mixtures of JP-4 and 10 percent ethanol on a weight/weight basis.

The Beech King Air 200 powers its "T" tail design with two PT6A-41 engines. The turboprop aircraft cruises at speeds in excess of 536 kph (333 mph) at 7.3 kilometers (24,000 feet) and has a gravity feed fuel system. The engine used for this alternate fuels program is the engine on the starboard side of the aircraft (reference 5).

TEST APPARATUS

The aircraft was modified to allow 10 percent of the total fuel flow to be replaced by ethanol during the testing program. The general location of the instrument rack, fuel tank, nitrogen tank, thermocouples, and fuel line system is illustrated in figure 1.

The aircraft carried an instrumentation rack consisting of a project power switch, a Zenith laptop computer, an Acrosystems™ data acquisition system, a power strip, a camera, and a Flo-scan™ fuel flow system. The temperatures recorded, using the acquisition system and computer, were the fuel temperature in the cabin tank and the fuel temperature of the mixture. An existing



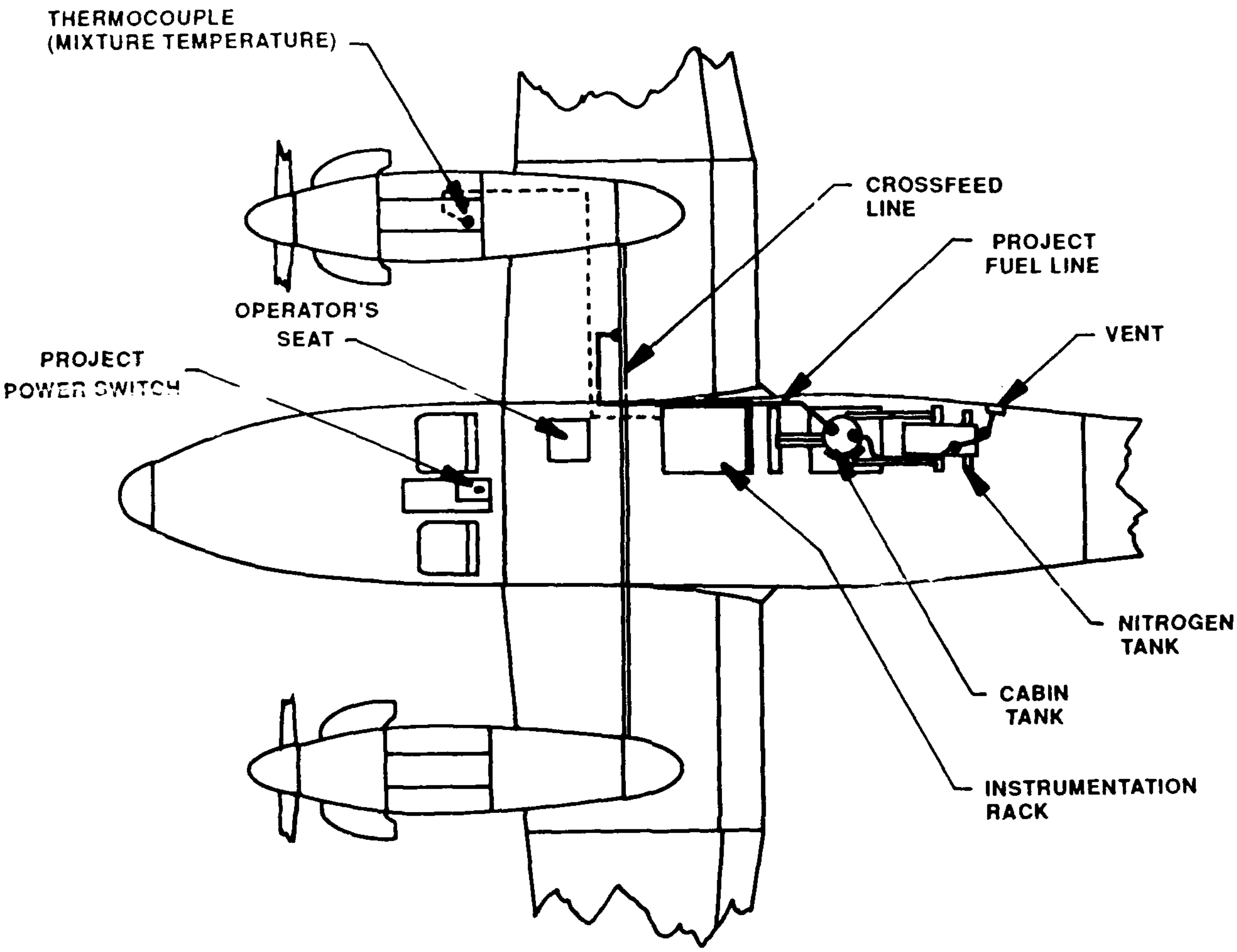


FIGURE 1. TEST EQUIPMENT INSTALLATION IN THE BEECH KING AIR 200

thermocouple line was utilized to measure the temperature of the fuel as it entered the engine. Pressure transducers were used to record tank pressure and aircraft fuel system pressure. The Flo-scan™ cabin tank fuel flow information was fed to the computer. To record aircraft instrumentation during flight, a VHS video camera was positioned on the rack. The layout of the rack is presented in figure 2. Project power (28-volt DC) was provided from the aircraft electrical system.

The 450-liter (15-gallon) cabin tank was equipped with a pressure relief value, a pressure transducer, a thermocouple, a quick connect fitting, and a Swagelock™ fitting connected to the fuel line. The nitrogen tank was equipped with a pressure gauge, a pressure regulator, a quick connect for attaching it to the fuel tank, and a pressure relief valve and discharge tube.

The project fuel line was installed in the space provided for a currently unused ferry tank line. A flow meter, an on/off valve (capable of regulating flow), a check valve, a pressure transducer, and a normally closed solenoid valve (which opened when project power was applied) were installed on the fuel line. The line ran from the fuel tank, along the instrument rack, and through a cover plate on the floor. The line then went through the pressure bulkhead and into the existing crossfeed line. A schematic of the system is shown in figure 3.

The altitude, interstage turbine temperature (ITT), torque, propeller resolutions per minute (rpm), percent rpm, fuel flow of the engines, oil pressure, outside air temperature (OAT), and general comments were recorded by the copilot using the existing aircraft instrumentation. Barometric pressure and ground temperature were obtained from ground observations.

TEST PROCEDURES

GENERAL.

The project personnel followed a set of standard setup procedures before every run. The technician filled the nitrogen tank and set the pressure regulator. For the initial ground runs, a fuel truck filled the cabin tank with JP-4. For all subsequent runs, a hand operated vane pump was used to fill the cabin tank from an ethanol barrel. After replacing the tank cap, the nitrogen tank was connected using a quick connect fitting to supply a constant pressure in the cabin fuel tank. The operator bolted the computer into place and connected the data acquisition system to the computer. After starting the engines, the pilot turned on project power. At this time, the operator turned on the computer and camera, loaded the project file, and set up the file for recording the data. After checking the tank pressure, the aircraft, and all equipment, the pilot proceeded to taxi to the runway.

Upon reaching the desired test point, the operator using the on/off valve, manually set the ethanol flow to 10 percent of the total fuel flow. Constant attention was given to establishing and regulating the ethanol flow.

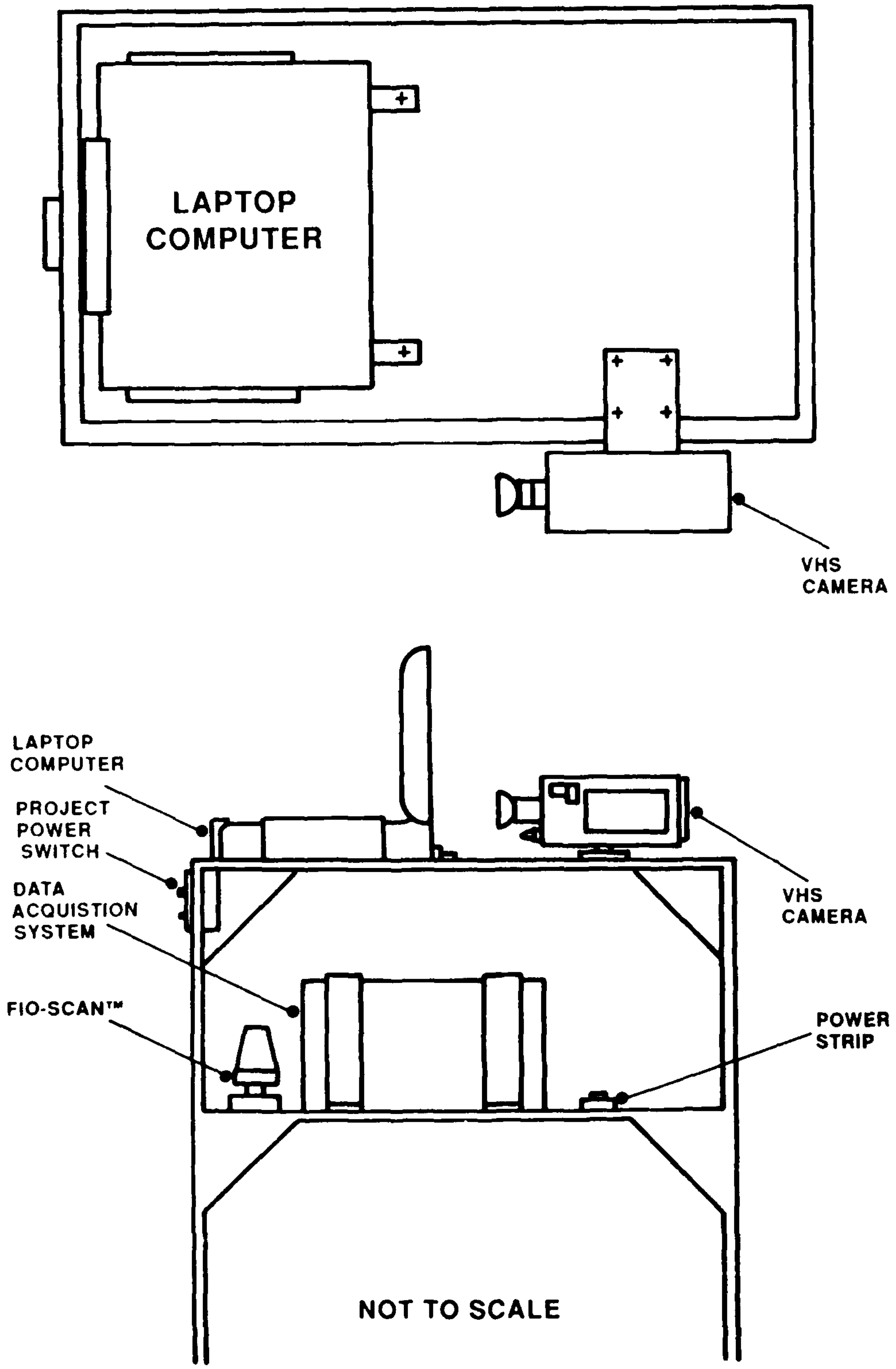


FIGURE 2. INSTRUMENTATION RACK - TOP AND SIDE VIEW

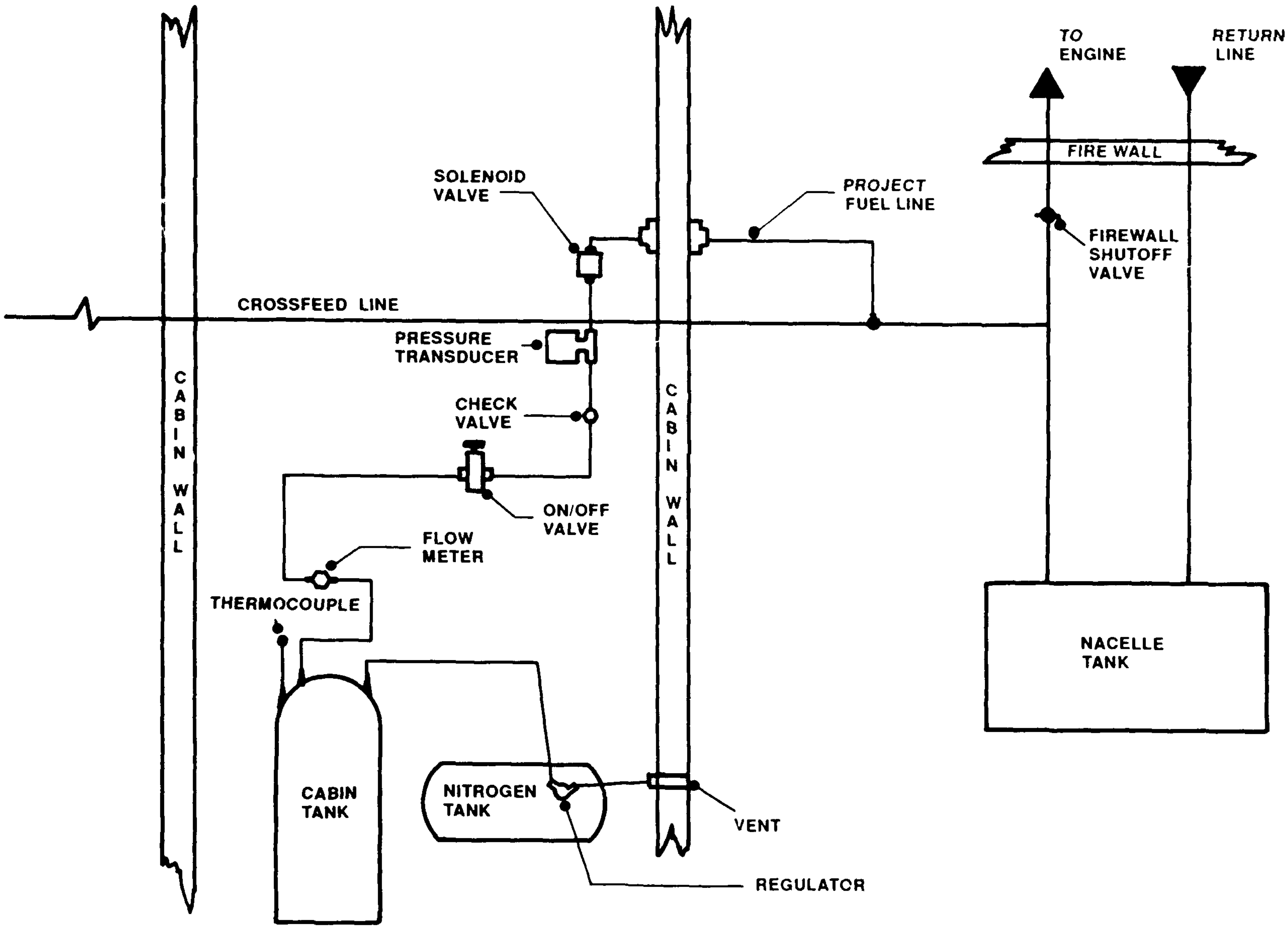


FIGURE 3. PROJECT FUEL SYSTEM

The operator and pilot recorded the data manually at predetermined test points, after allowing conditions to stabilize for at least 2 minutes.

A set of standard shutdown procedures was followed after every run. On separate disks, the data file was saved and backed up. After the camera, computer, and data acquisition systems were shut down, the project power was turned off. On the ground, pressure was released from the tank system and the computer was removed from the aircraft.

All data were converted to standard day, sea level conditions (references 6 and 7), calculated, plotted, and analyzed.

GROUND RUN TESTS.

The ground runs, conducted to check and document all systems before flight testing, consisted of four different types.

For the initial ground run, the cabin tank was fueled with JP-4. The engine was operated in ground idle, using all data acquisition systems. The operator turned on the cabin flow, at ground idle, for 2 minutes. The test engine was then shut down, to review the data.

The cabin tank was fueled with JP-4 for the baseline ground runs. Within the limits allowed for ground operation, the test engine was operated at the following power settings: ground idle, high idle, descent/approach, 55, 60, 65, 70, 75, 80, and 90 percent of maximum continuous power. For this project and in practice, maximum continuous power was equal to takeoff power.

For the ethanol performance ground runs, the tank was fueled with ethanol. The test engine was operated, using the dual fuel system, at the following power settings: low idle, high idle, takeoff, descent/approach, and 55, 60, 65, 70, 75, 80, and 90 percent of maximum continuous power.

The tank was fueled with JP-4 for the performance verification runs. The test engine was operated, using the dual fuel system, at the following power settings: takeoff, 75 and 60 percent of maximum continuous power, and ground idle.

FLIGHT TEST.

Three different flight test profiles were performed: step climb, altitude endurance, and climb to altitude. All flight tests were conducted with ethanol in the cabin fuel tank.

Step Climb. A step climb of 6,000-foot intervals was conducted to a 30,000-foot pressure altitude. Maximum continuous power was maintained during the entire test run. At each step, a baseline reading was recorded. The ethanol was turned on for 5 minutes, then the ethanol was turned off to climb to the next altitude point. This on/off sequence was repeated with each altitude step. Another run was conducted using a power setting of maximum range (1700 rpm and ITT of 700 °C).

Altitude Endurance. This test consisted of climbing to a selected pressure altitude and establishing a predetermined power setting. A baseline reading

was recorded. Aircraft operation, using the dual fuel system, was established and data were recorded every 5 minutes. If necessary, the ITT was reset to match the ITT recorded before the dual fuel system was employed. The dual fuel operations were maintained for 100 minutes, then the ethanol was turned off to obtain a second baseline reading. The above sequence was undertaken for combinations of the following altitude and rpm ratings: 6,000, 12,000, 18,000, 24,000 feet; and 1900, 1800, 1700 rpm.

Climb to Altitude. A climb to the 30,000-foot pressure altitude was conducted using the dual fuel system. Maintaining an rpm rating of 1900, the data were recorded every 3,000 feet. The ethanol flow was constantly adjusted to maintain a 10 percent flow, based on the total aircraft fuel flow. Upon attaining a pressure altitude of 30,000 feet, data were documented every 5 minutes, until the total time on ethanol reached 100 minutes. The ethanol was turned off and a baseline reading was recorded.

The sequence above was repeated using an rpm rating of maximum range or 1700.

SUMMARY OF RESULTS

To measure the overall effects of 10 percent ethanol on the aircraft engine, a set of hot section inspections was performed; one inspection before the installation of the instrumentation and one after the removal of the instrumentation from the aircraft. Of the 37 hours of total testing time, a total of 20.3 hours was run on the 10 percent ethanol mixture. This was insufficient time to draw any firm conclusions, however, the inspections revealed no immediate damage or decay caused by operating on 10 percent ethanol mixtures.

GROUND RUN ANALYSIS

Ambient conditions for all ground runs were close to standard, except for humidity, therefore the data were not corrected to perform the ground run analysis. The data revealed an average increase in the ITT of 0.6 percent and a 10 percent drop in the torque when the fuel was changed from straight JP-4 to a mixture of 10 percent ethanol and 90 percent JP-4. The power settings for all ground runs were initially set by torque and the torque ranged from 1200 ft·lbf (1627 N·m) (descent/approaoh) to 2230 ft·lbf (3023 N·m) (maximum continuous power). For the ethanol run, a limiting oil temperature prevented the test pilot from establishing the maximum continuous power setting. In this case, a torque of 2015 ft·lbf (2732 N·m) was the highest reading observed.

Figure 4 illustrates the power versus the ITT for the two JP-4 ground runs and the one ground run using the ethanol mixture. An analysis showed an average power decrease of 1.7 percent when comparing the JP-4 runs to the ethanol run. The average power difference between the two JP-4 ground runs, which was less than 0.6 percent, was insignificant.

The fuel flow, as plotted in figure 5 against ITT, increased an average of 3.1 percent when the ethanol was used. The flow increase tended to be higher at higher power settings. The 0.05 percent average fuel flow difference between the two ground runs was negligible.

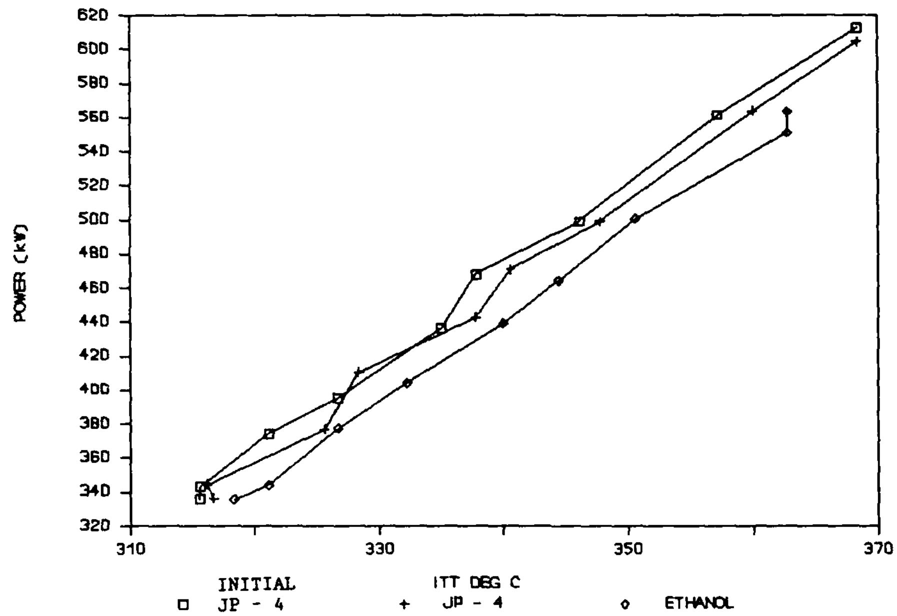


FIGURE 4. POWER VERSUS ITT FOR THE GROUND RUNS

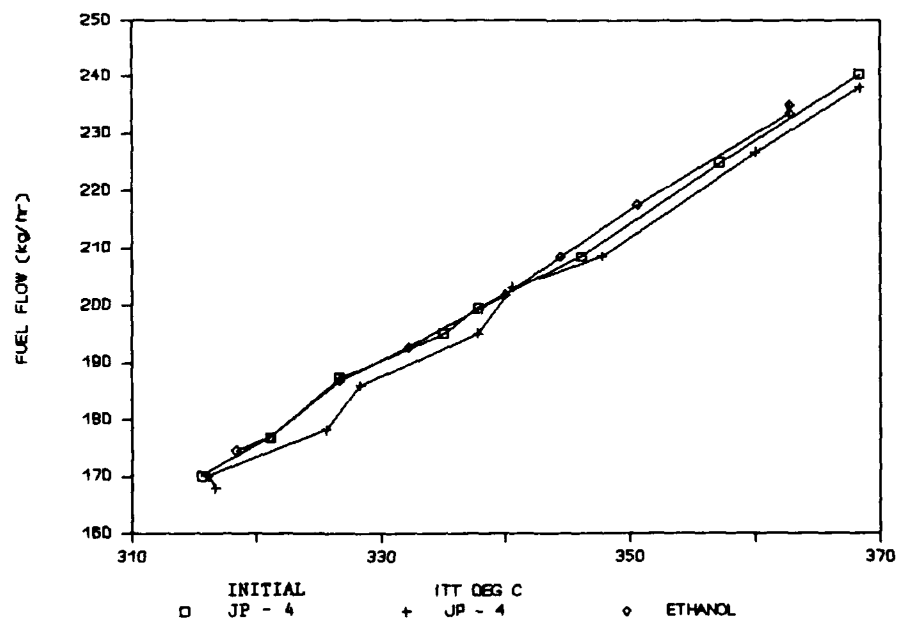


FIGURE 5. FUEL FLOW VERSUS ITT FOR THE GROUND RUNS

Figure 6 revealed that the brake specific fuel consumption of the two JP-4 runs was within 0.7 percent of one another. The overall brake specific fuel consumption of the ethanol mixture was consistently 3.9 percent higher. This compares favorably with the 3.89 percent calculated change in energy density resulting from a 10 percent mixture of ethanol and JD-4. In general, these trends agreed with the observations noted during dynamometer tests using the T-63 Turboshaft engine (reference 3).

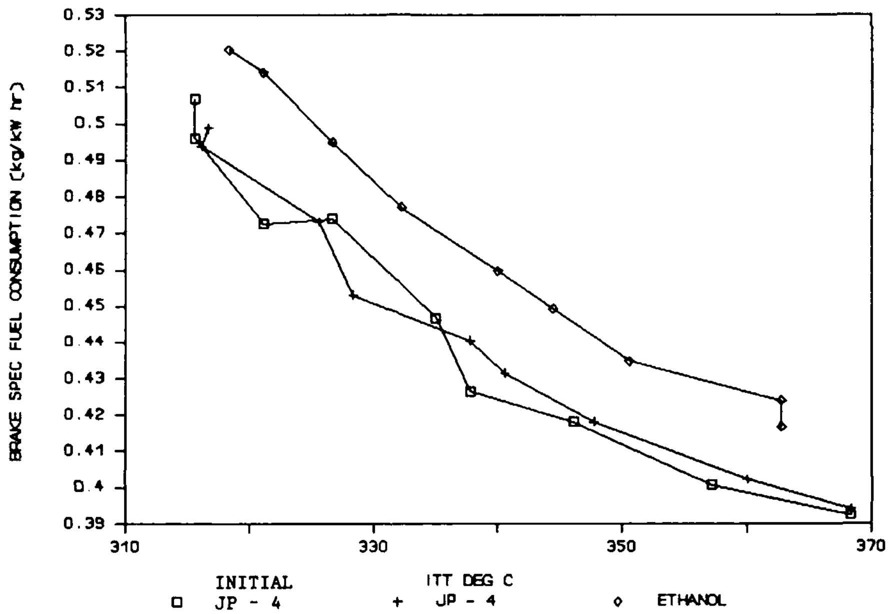


FIGURE 6. BRAKE SPECIFIC FUEL CONSUMPTION VERSUS ITT FOR THE GROUND RUNS

STEP CLIMB ANALYSIS

As with the ground runs, the shifts between JP-4 and the 10 percent ethanol mixture during the step climb produced significant differences in all parameters. When reviewing the raw data for the step climbs, the torque and ITT were always lower when the ethanol mixture fueled the aircraft. Between the two runs, the average torque drop was 5.4 percent and the average ITT drop was 2 percent. All subsequent step climb data were corrected to sea level standard conditions for comparison and analysis.

The power setting for the maximum performance climb was set at 1900 rpm, at either the maximum allowable torque for that altitude or within the ITT limitation of 720 °C. Figures 7, 8, and 9 reveal the change in power, fuel flow, and brake specific fuel consumption for different altitudes when operating at maximum continuous power on the ethanol mixture. For this run, the power was an average of 4.6 percent lower and the average fuel flow decreased by 0.5 percent with ethanol. The calculated change in energy density for the ethanol mixture was 3.89 percent and thus should translate into a similar increase in brake specific fuel consumption. Under these conditions, the data showed a significant average increase of 4.5 percent for

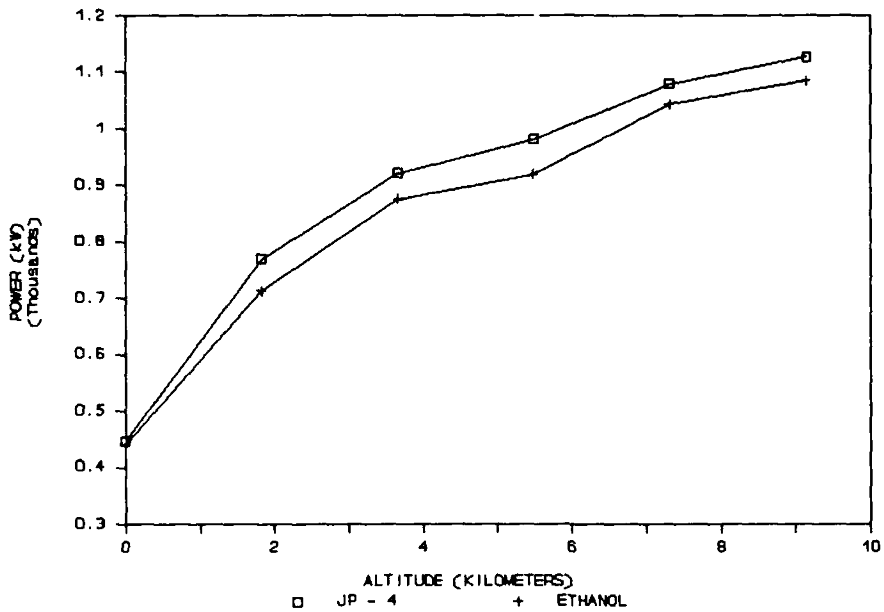


FIGURE 7. POWER VERSUS ALTITUDE FOR THE STEP CLIMB AT MAXIMUM CONTINUOUS POWER

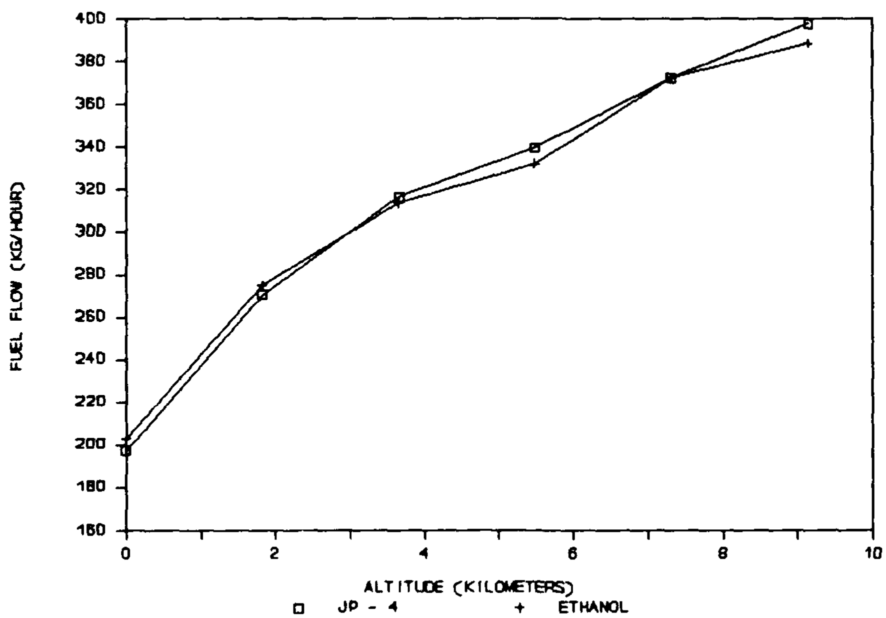


FIGURE 8. FUEL FLOW VERSUS ALTITUDE FOR THE STEP CLIMB AT MAXIMUM CONTINUOUS POWER

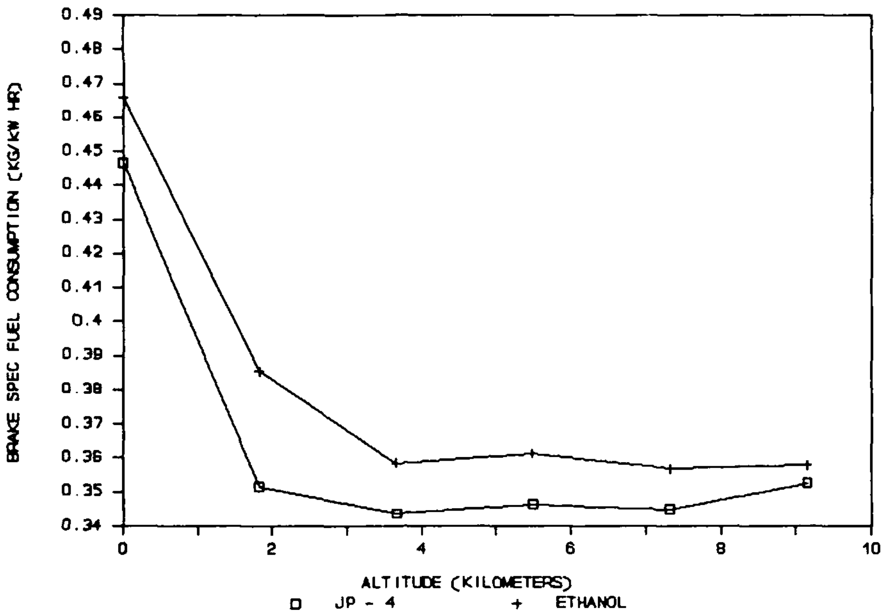


FIGURE 9. BRAKE SPECIFIC FUEL CONSUMPTION VERSUS ALTITUDE FOR THE STEP CLIMB AT MAXIMUM CONTINUOUS POWER

the brake specific fuel consumption. Overall, the differences in the brake specific fuel consumptions were lower for higher altitudes.

The power setting for the step climb using the maximum range power was 1700 rpm and an ITT of 700 °C. Figures 10, 11, and 12 show changes in the ethanol line where the pilot reset the power. In these instances, the pilot reset the ITT to the ITT recorded before the ethanol was turned on. For this run, the average power loss was 4.9 percent and the average fuel flow increased by 0.3 percent when the ethanol was turned on. The brake specific fuel consumption rose 5.9 percent when the ethanol mixture was burned. The difference in brake specific fuel consumption tended to decrease with altitude; however, the average change was still slightly greater than the 3.89 percent change in energy density.

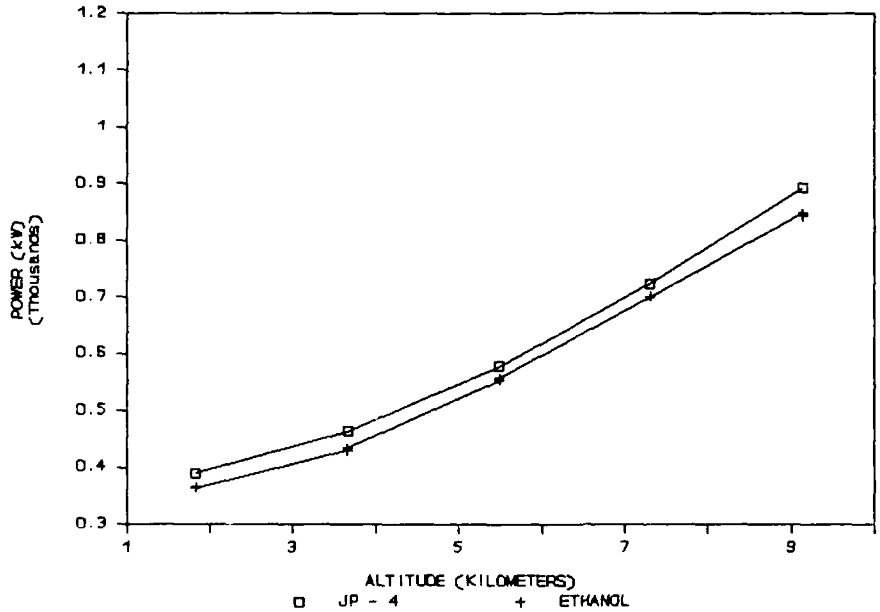


FIGURE 10. POWER VERSUS ALTITUDE FOR THE STEP CLIMB AT MAXIMUM RANGE

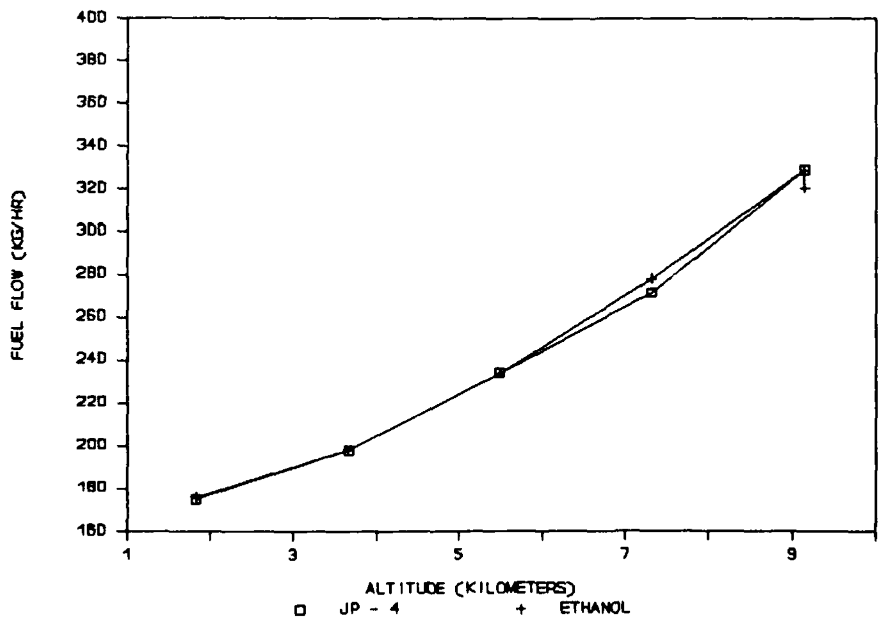


FIGURE 11. FUEL FLOW VERSUS ALTITUDE FOR THE STEP CLIMB AT MAXIMUM RANGE

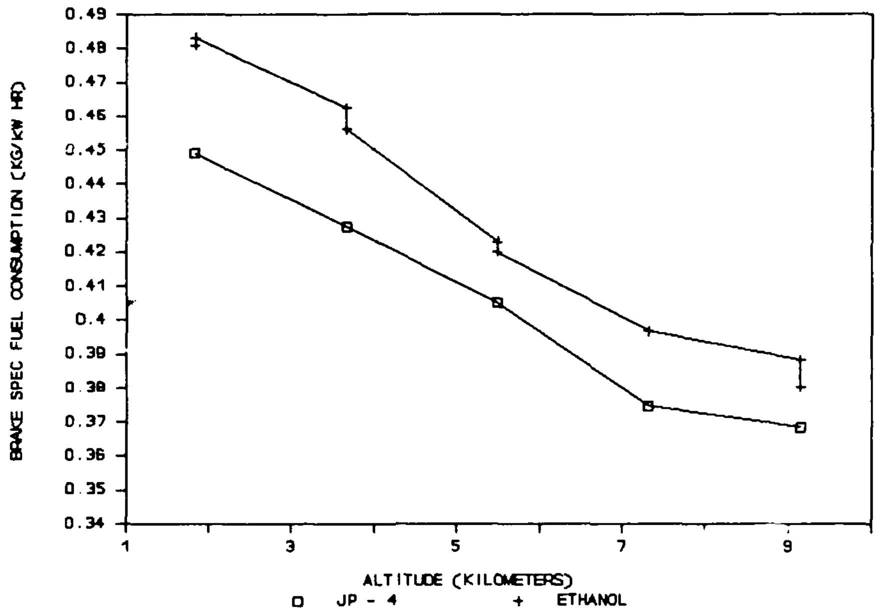


FIGURE 12. BRAKE SPECIFIC FUEL CONSUMPTION VERSUS ALTITUDE FOR THE STEP CLIMB AT MAXIMUM RANGE

During the step climbs, the pilots reported stagger between the right and left throttle levers. Typically, the throttle for the engine operating on ethanol, was further advanced. For maximum power operations above 18,000 feet, the throttle was full forward, yet the engine was not up to power or ITT. When comparing the step climbs with the ground runs at sea level, altitude appeared to affect the brake specific fuel consumption. It is possible the combination of density altitude and nonstandard fuel resulted in operations so far from the design point that a higher brake specific fuel consumption resulted.

ALTITUDE ENDURANCE ANALYSIS

To analyze the altitude endurance information, all data were converted to standard sea level conditions. In figures 13 to 18 and in appendix A, the curves are marked "ETHANOL" to note where the test fuel was turned off and on. The label "JP-4" indicates operations on JP-4 only, and "RESET" shows where changes in power were made. (During the course of the run, the pilots reset the power by matching the ITT of engine No. 2 (the test engine) with the ITT of engine No. 1).

Figures 13, 14, and 15 reveal a sample of one typical altitude endurance run. During run 1 at 18,000 feet, the power, fuel flow, and brake specific fuel flow fluctuated slightly throughout the run due to turbulence. For the power setting of 1900 rpm, the initial power dropped 2.7 percent. After the ITT reset, the power was an average of 3.8 percent lower than operation on neat JP-4 with the same power lever position. The fuel flow increased an average of 0.7 percent before the reset and fell slightly to an average increase of 0.6 percent after the reset. For the brake specific fuel consumption, a 3.9 percent average increase was calculated. The average rose to 4.8 percent after the reset. The analysis and plots for the 18,000-foot, 1900-rpm run, provide a representation of all the altitude endurance runs conducted.

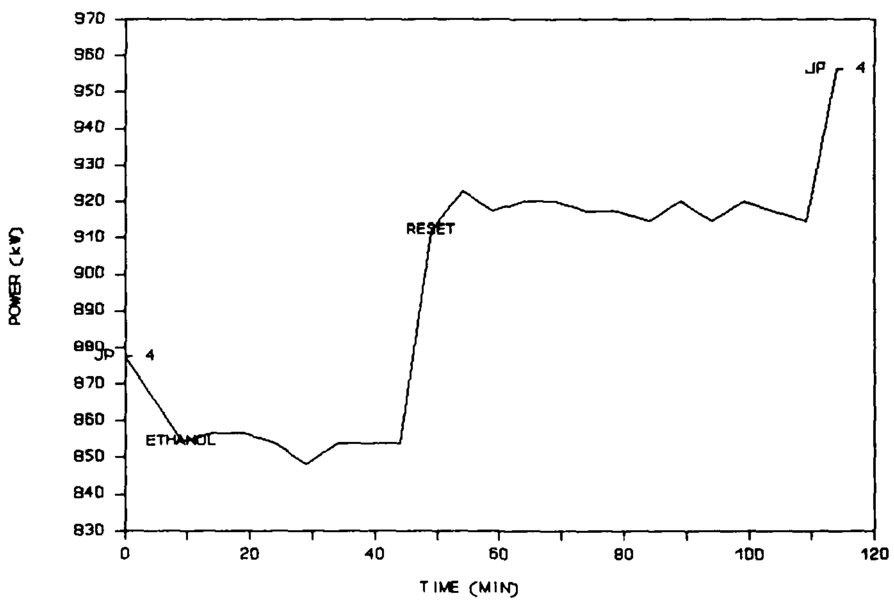


FIGURE 13. CHANGES IN POWER FOR THE 18,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM CONTINUOUS POWER

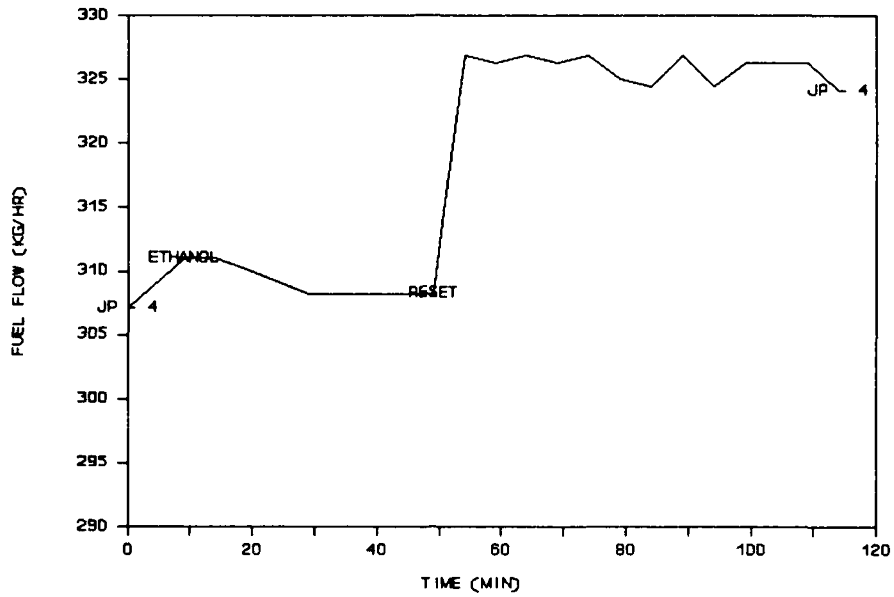


FIGURE 14. CHANGES IN FUEL FLOW FOR THE 18,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM CONTINUOUS POWER

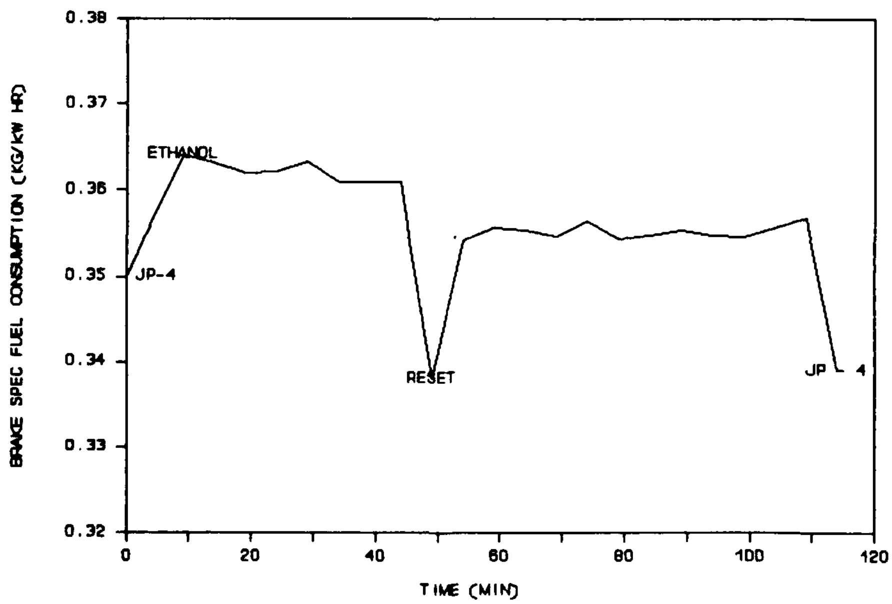


FIGURE 15. CHANGES IN BRAKE SPECIFIC FUEL CONSUMPTION FOR THE 18,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM CONTINUOUS POWER

Figures 16, 17, and 18 illustrate the power, fuel flow, and brake specific fuel consumption fluctuations in a 30,000-foot climb to altitude run at 1900 rpm and maximum continuous torque. The climb was conducted on the ethanol mixture; therefore, the comparative baseline readings were taken at the end of the run. The ITT was not reset at any time during the run. Traffic and holding patterns caused slight fluctuations in the power and fuel flow. On the whole, the corrected power and fuel flow rose steadily with the altitude increases. The brake specific fuel consumption fluctuated greatly during the climb, yet reached a peak at 27,000 feet. After leveling off, an average percentage decrease in power of 4.0 percent was calculated using the 30,000-foot JP-4 data recorded at the end of the run. The fuel flow initially increased; however, average fuel flow for the run at 30,000 feet decreased by 0.1 percent. The decrease in fuel flow could be a result of not resetting the ITT. The analysis plot for the 30,000-foot, 1900-rpm run is similar to the 30,000-foot, 1700-rpm run in appendix A.

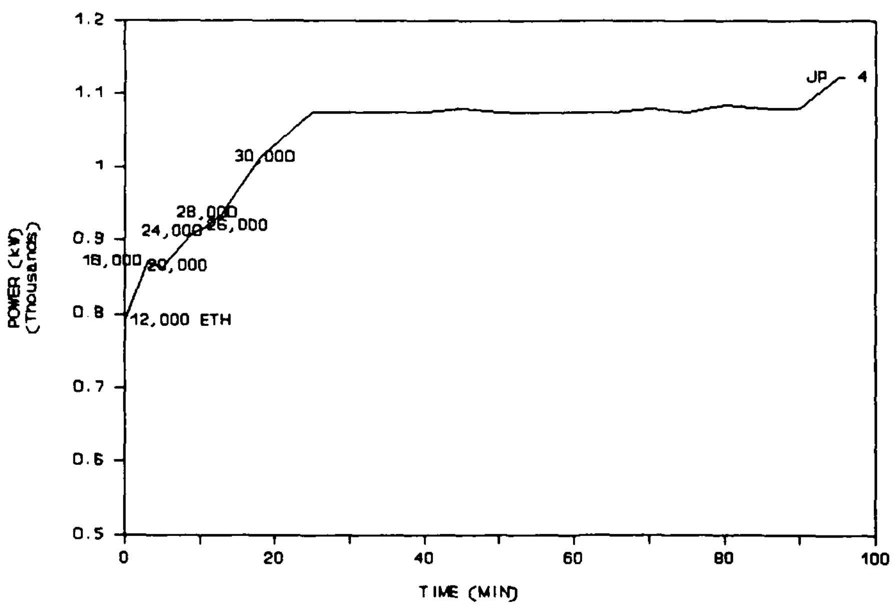


FIGURE 16. CHANGE IN POWER FOR THE CLIMB TO ALTITUDE AT MAXIMUM CONTINUOUS POWER

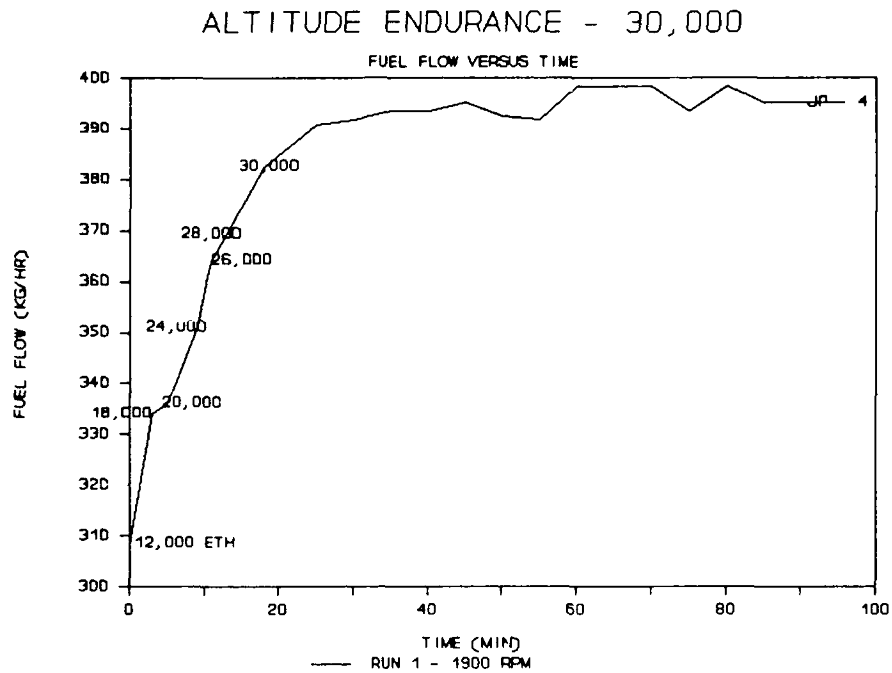


FIGURE 17. CHANGE IN FUEL FLOW FOR THE CLIMB TO ALTITUDE AT MAXIMUM CONTINUOUS POWER

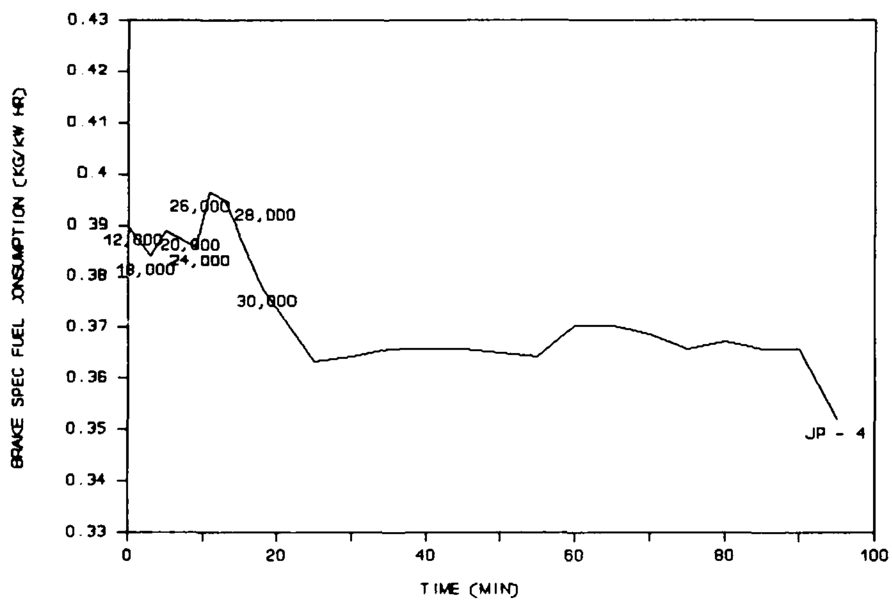


FIGURE 18. CHANGE IN BRAKE SPECIFIC FUEL CONSUMPTION FOR THE CLIMB TO ALTITUDE AT MAXIMUM CONTINUOUS POWER

For the remaining altitude endurance and climb to altitude runs, the figures can be referenced in appendix A. The analysis comparing the average power, average fuel flow, and average brake specific fuel consumption from when the setting was established on JP-4 to before the ITT was reset is located in table 1. Table 2 documents the average change for all altitude endurance runs after the ITT was reset. In table 2, the power on the ethanol mixture is compared against the power on JP-4 at the end of the run. In most cases, the increase in brake specific fuel consumption was greater than the calulated change in energy density.

TABLE 1. AVERAGE CHANGES IN THE ALTITUDE ENDURANCE RUNS BEFORE AN ITT RESET

ALTITUDE	RPM	CHANGE IN POWER, %	CHANGE IN FUEL FLOW, %	CHANGE IN BRAKE SPECIFIC FUEL CONSUMPTION, %
6,000	1900	-1.36	2.18	3.57
6,000	1700	-4.17	1.14	5.55
12,000	1900	-1.55	1.04	2.63
12,000	1800	-3.28	0.42	3.83
12,000	1700	-2.32	0.80	3.20
18,000	1900	-2.68	0.71	3.48
18,000	1800	-2.93	1.08	4.11
18,000	1700	-2.72	-0.04	2.76
24,000	1900	-2.49	0.85	3.43
30,000	1900	-3.99	-0.09	4.06
30,000	1700	-6.99	-1.16	6.35

TABLE 2. AVERAGE CHANGES IN THE ALTITUDE ENDURANCE RUNS AFTER AN ITT RESET

ALTITUDE	RPM	CHANGE IN POWER, %	CHANGE IN FUEL FLOW, %	CHANGE IN BRAKE SPECIFIC FUEL CONSUMPTION, %
6,000	1900	no reset	no reset	no reset
6,000	1700	no reset	no reset	no reset
12,000	1900	-4.08	0.00	4.25
12,000	1800	-4.05	0.00	4.23
12,000	1700	-3.78	1.23	5.21
18,000	1900	-3.97	0.61	4.78
18,000	1800	-4.17	1.54	6.23
18,000	1700	-1.76	1.18	2.99
24,000	1900	no reset	no reset	no reset
30,000	1900	no reset	no reset	no reset
30,000	1700	no reset	no reset	no reset

As a whole, text describing figures 13 through 18, conveys the basic data analysis; however, a few points must be highlighted. At altitudes below 18,000 feet, turbulence caused slight fluctuations in power. During the 12,000-, 18,000-, and 24,000-foot runs, the ITT was reset at least once. The fuel flow reached capacity during the 12,000-foot runs at 1900- and 1800-rpm runs; consequently, no change in fuel flow occurred when the ethanol was shut off. Initially, the fuel flow for the 18,000-foot, 1700-rpm power setting increased, but the total flow gradually decreased below the total JP-4 only flow until the ITT was reset. For the same run, a descent on ethanol was incorporated into the run after the baseline reading. No apparent difficulties were observed, however, exact data were not recorded. Lastly, only one run was conducted at 24,000 feet and that run was terminated due to a bad oil pressure sensor.

RELATED OBSERVATIONS

During the altitude endurance runs a wide range of temperatures were recorded for the ethanol mixture. The largest changes in temperature, were observed during the 30,000-foot runs. The initial temperature of the fuel at takeoff was about 22.4 °C (72.8 °F). At 30,000 feet during the 1700-rpm run, the coldest temperature observed for the mixture was -8.6 °C (16.5 °F) . The temperature for the mixture fell to a low of -9.7 °C (14.5 °F) during the 30,000-foot run at 1900 rpm (see figure 19). The spikes in the curve indicate where the power was reset during the climb. The temperature variation and the extremely cold temperatures of the ethanol mixture were expected to cause problems with phase separation, however no problems were noted.

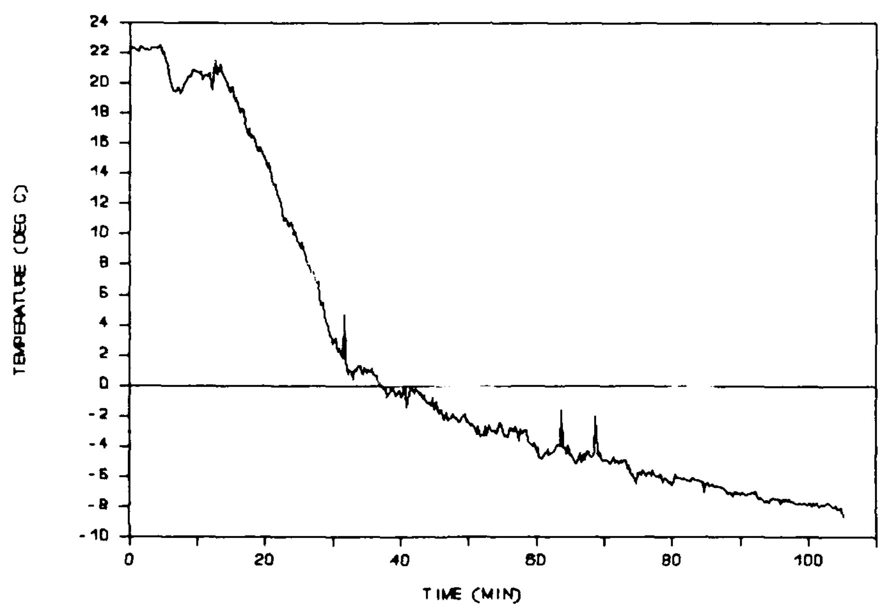


FIGURE 19. CHANGE IN FUEL TEMPERATURE DURING THE CLIMB TO ALTITUDE AT MAXIMUM CONTINUOUS POWER

CONCLUSIONS

At a given interstage turbine temperature, the power developed was lower when operating on the ethanol/JP-4 mixture than when operating on straight JP-4. In addition, brake specific fuel consumption increased more than was expected based on the change in energy density. The combination of these phenomena indicate that the combustion properties of the mixture are different from the neat fuel.

At various altitudes in flight, the fuel control unit did not have sufficient command authority to maintain the power output level, while operating on the ethanol/JP-4 mixture. This implies that some redesign may be required to keep the aircraft performance levels at the original specifications.

No operational problems were noted, except for throttle stagger, which was caused by the lower power output associated with the use of the ethanol/JP-4 mixture in the test engine.

REFERENCES

1. Corp, Paul, Laboratory Investigations into the Effects of Adding Alcohol to Turbine Fuel, Federal Aviation Administration Technical Center, Atlantic City International Airport, NJ, 08405, Report No. DOT/FAA/CT-TN88/25, July, 1988.

2. Block, Mark, ASTM Tests of Alcohols in Turbine Fuels, Federal Aviation Administration Technical Center, Atlantic City International Airport, NJ, 08405, Report No. DOT/FAA/CT-TN88/36, September, 1988.

3. Ferrara, Augusto M., Turbine Fuel Alternatives (Near Term), Federal Aviation Administration Technical Center, Atlantic City International Airport, NJ, 08405, Report No. DOT/FAA/CT89/23, October, 1989.

4. Romano, Ronald, T63-A-5A Engine Modified Fuel Evaluation, Naval Air Propulsion Center, Trenton, NJ, 08628-0176, Report No. NAPC-LR-89-12, June, 1989.

5. Pilot's Operating Handbook and FAA Approved Airplane Flight Manual, Super King Air 200, Beechcraft, Wichita Kansas, Part No. 101-590010-127, February, 1981.

6. The Aircraft Gas Turbine Engine and Its Operation, Pratt and Whitney Aircraft, East Hartford Connecticut, Part No. PWA 0 I 200, August, 1970

7. Aeronautical Vestpocket Handbook, Pratt and Whitney Aircraft, East Hartford Connecticut, Part No. 795000, August, 1986.

APPENDIX A
Altitude Endurance Data

The appendix contains three types of plots for the altitude endurance runs, power versus time, fuel flow versus time, and brake specific fuel consumption versus time. All data are corrected to sea level conditions.

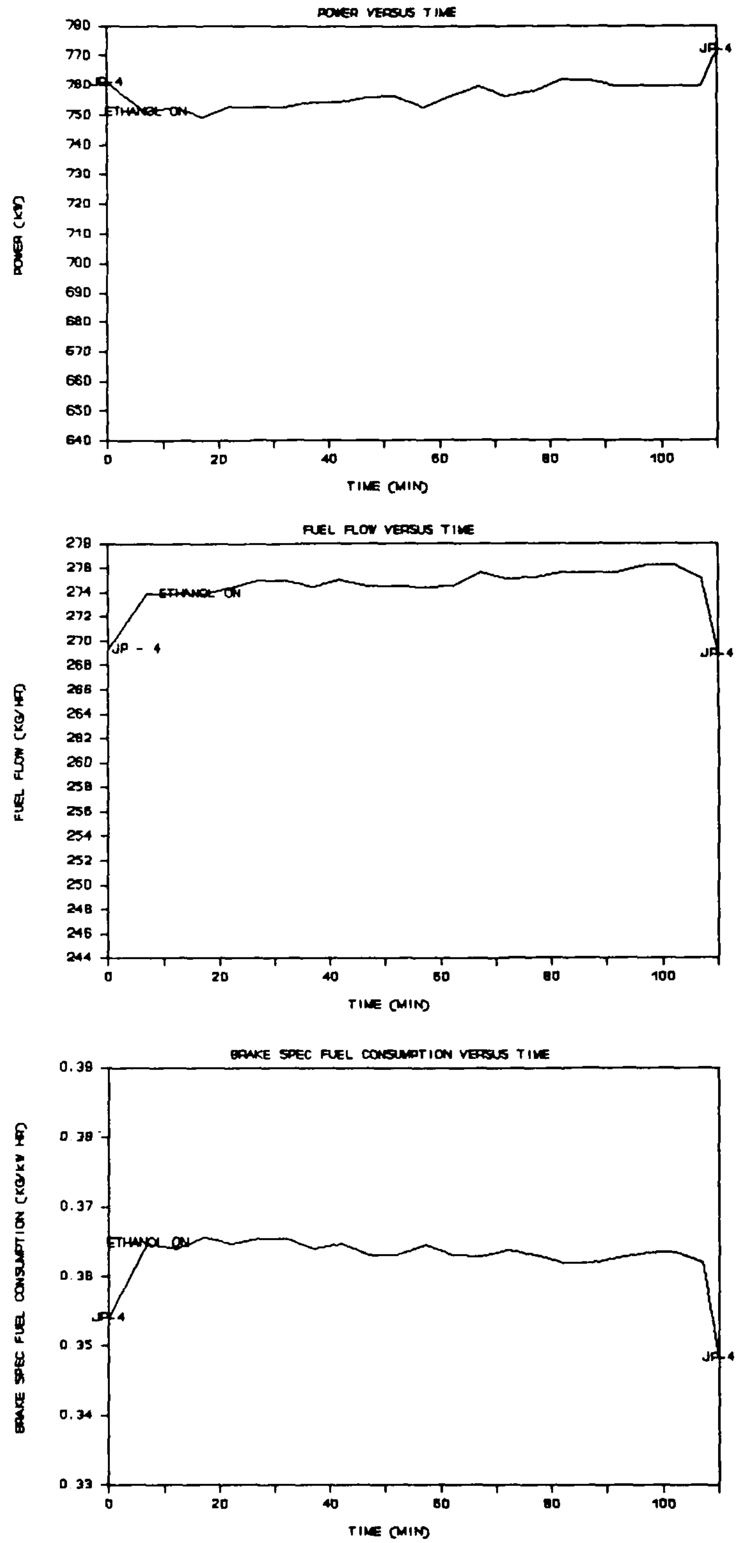


FIGURE A-1. EFFECTS OF 10 PERCENT ETHANOL DURING A 6,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM CONTINUOUS POWER

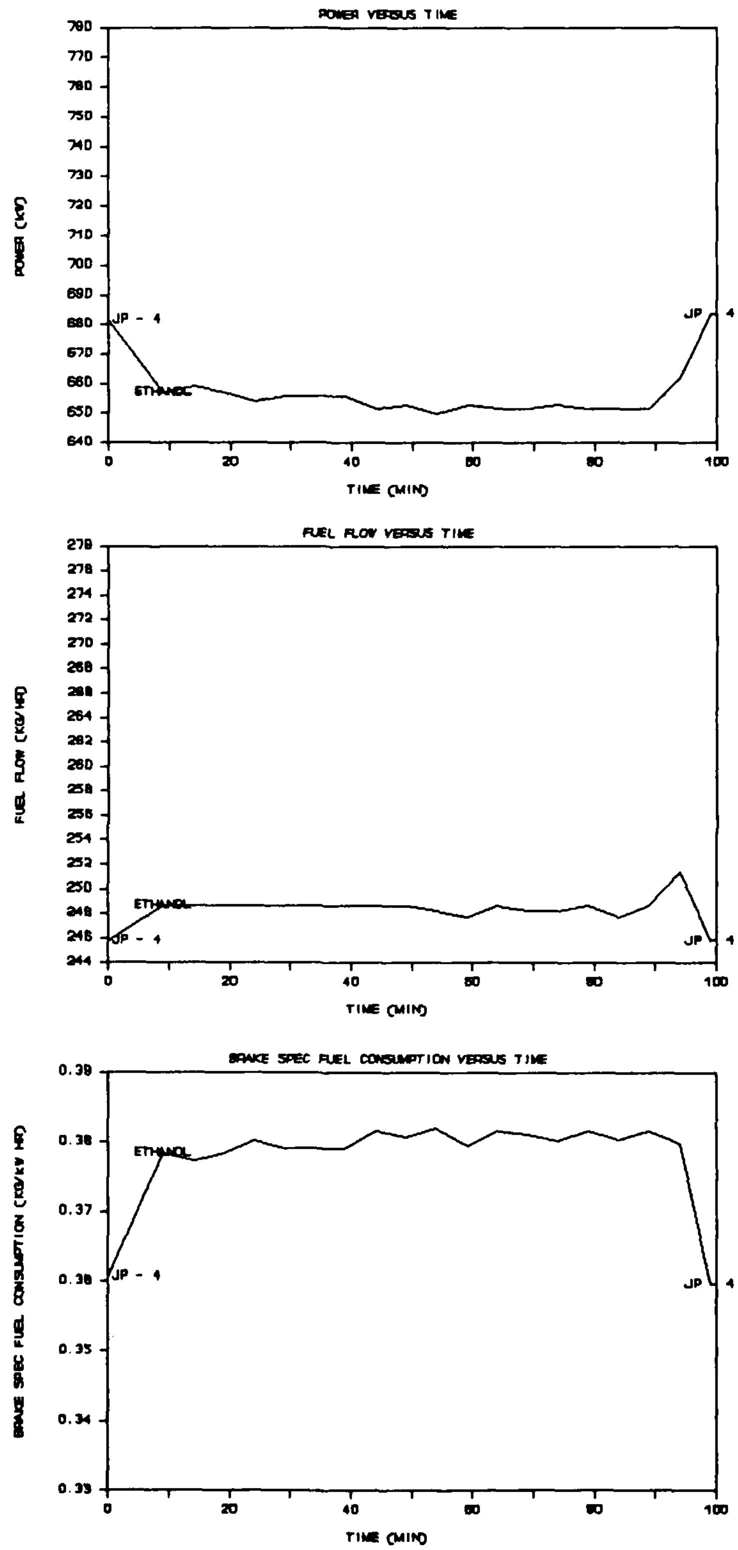


FIGURE A-2. EFFECTS OF 10 PERCENT ETHANOL DURING A 6,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM RANGE

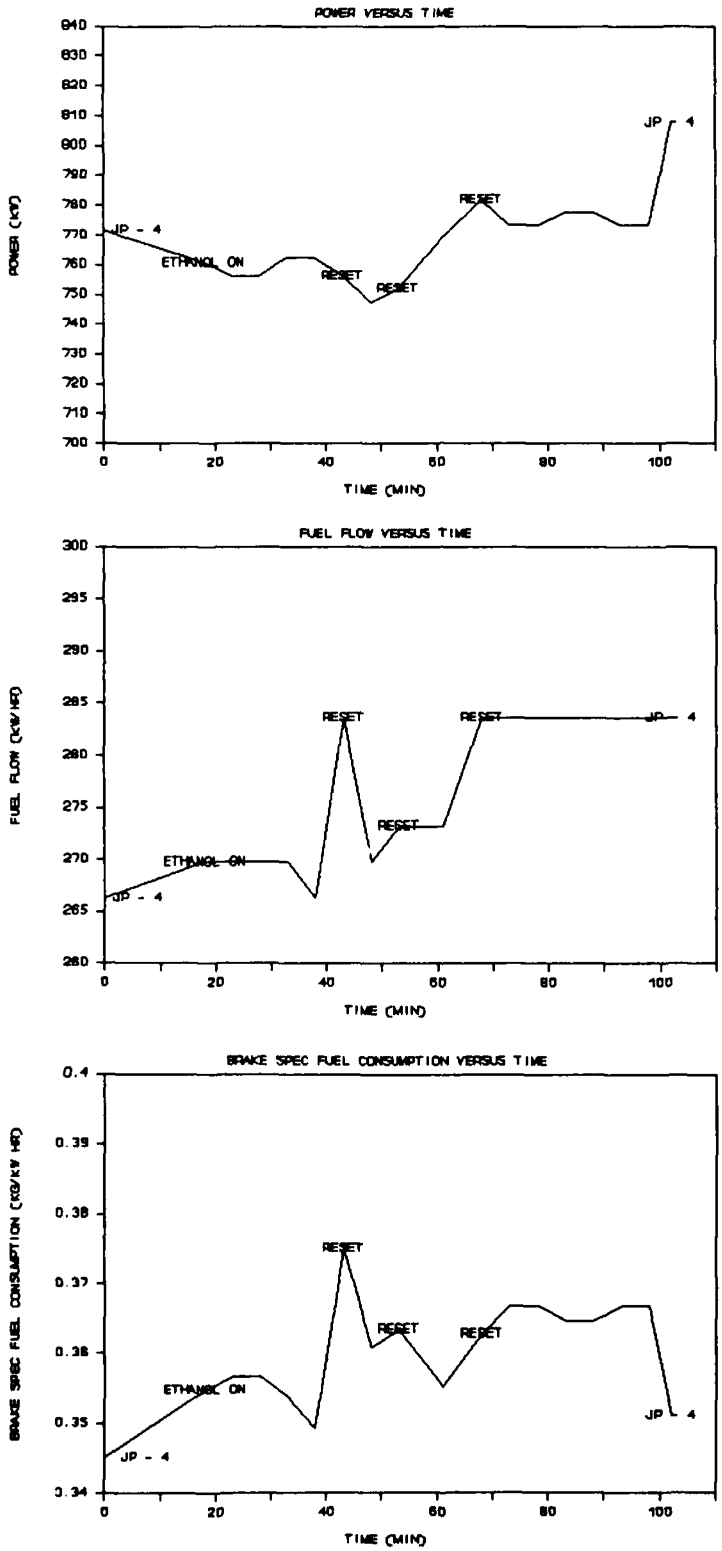


FIGURE A-3. EFFECTS OF 10 PERCENT ETHANOL DURING A 12,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM CONTINUOUS POWER

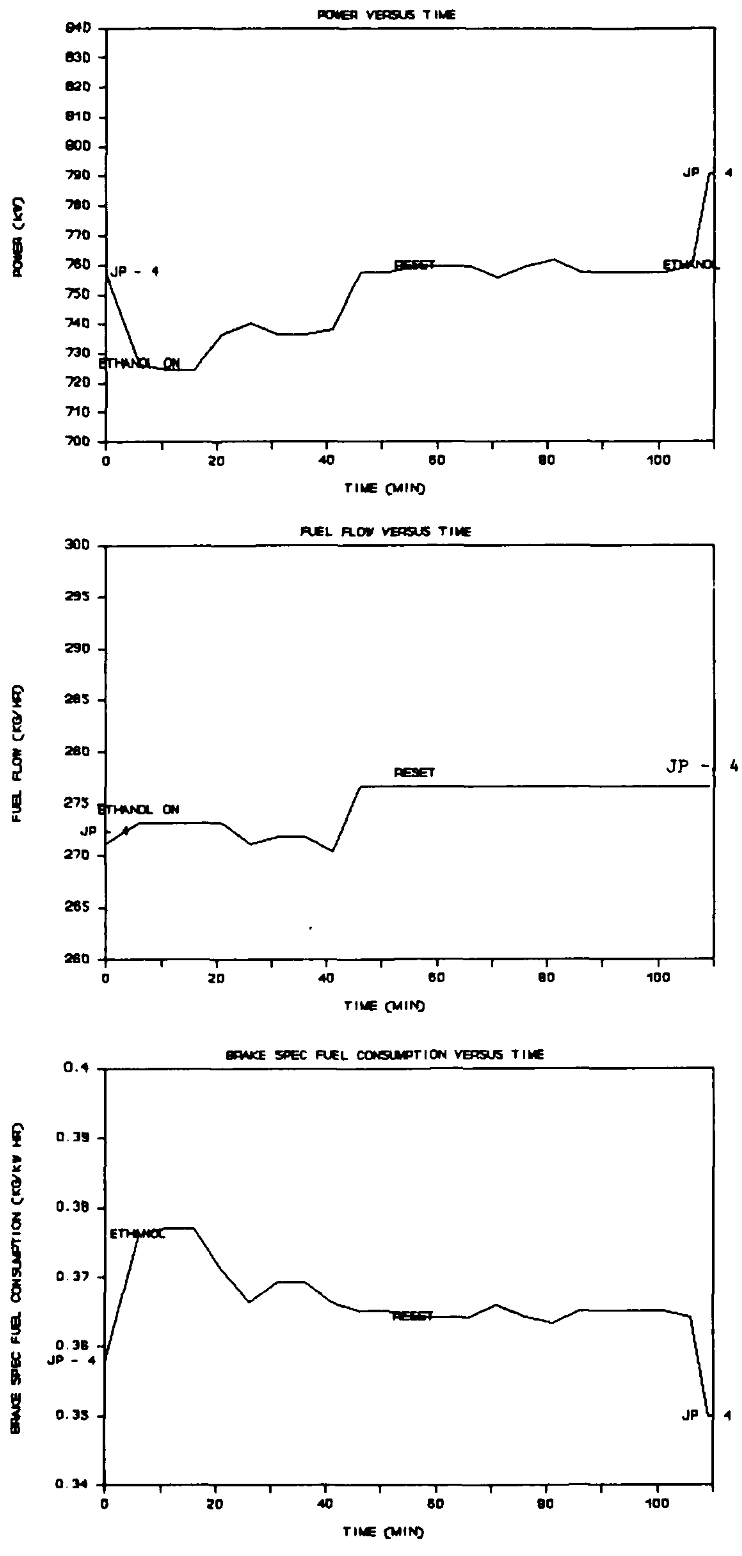


FIGURE A-4. EFFECTS OF 10 PERCENT ETHANOL DURING A 12,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM CRUISE POWER

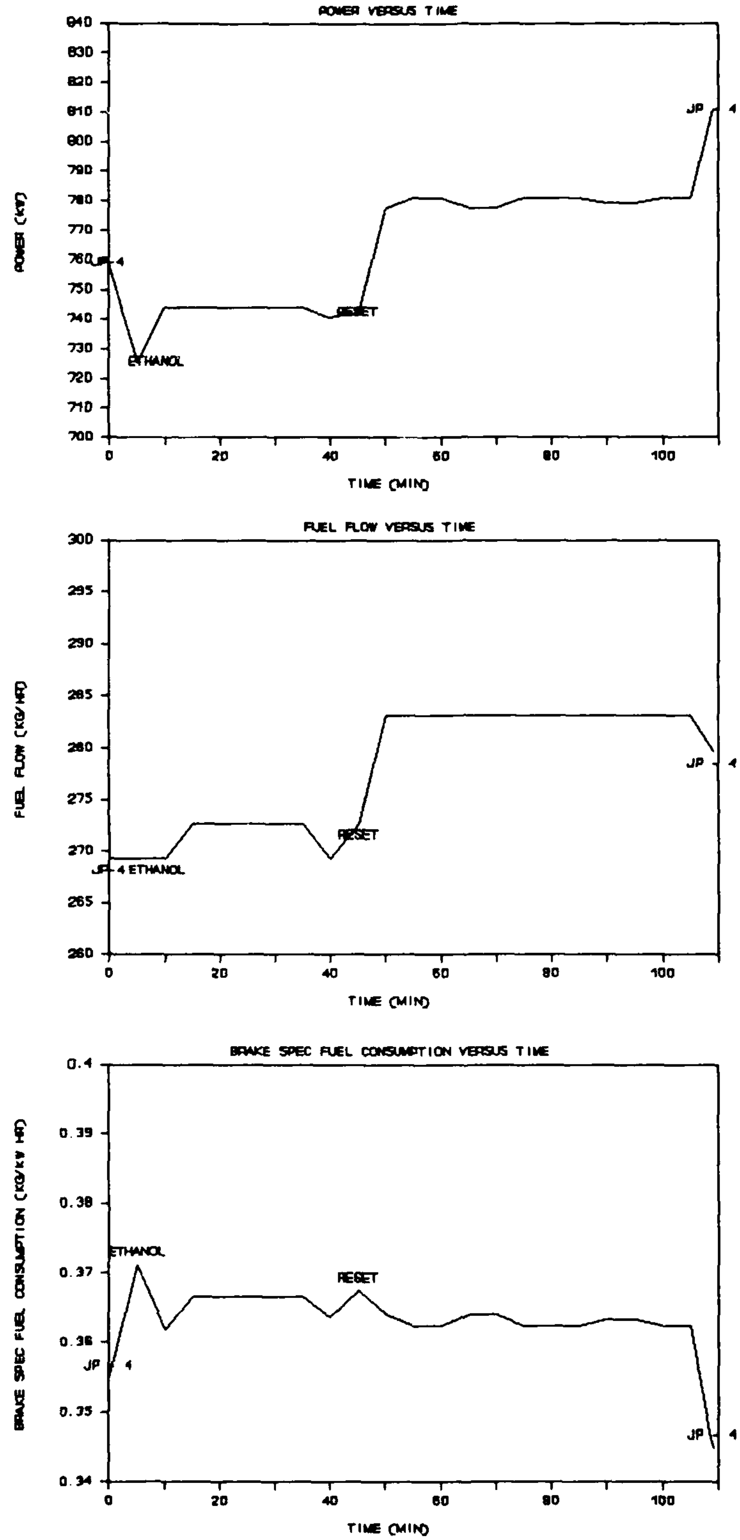


FIGURE A-5. EFFECTS OF 10 PERCENT ETHANOL DURING A 12,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM RANGE POWER

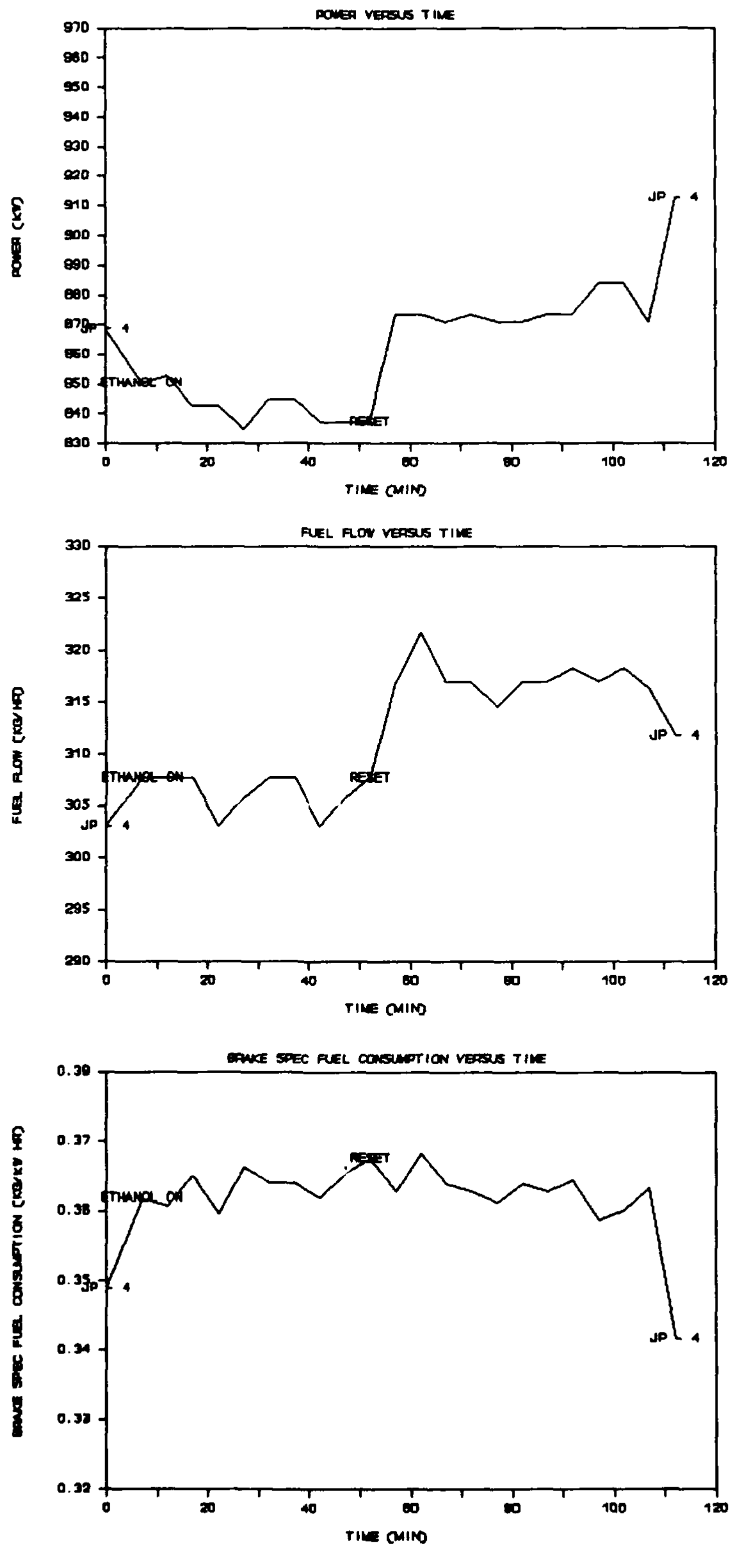


FIGURE A-6. EFFECTS OF 10 PERCENT ETHANOL DURING AN 18,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM CRUISE POWER

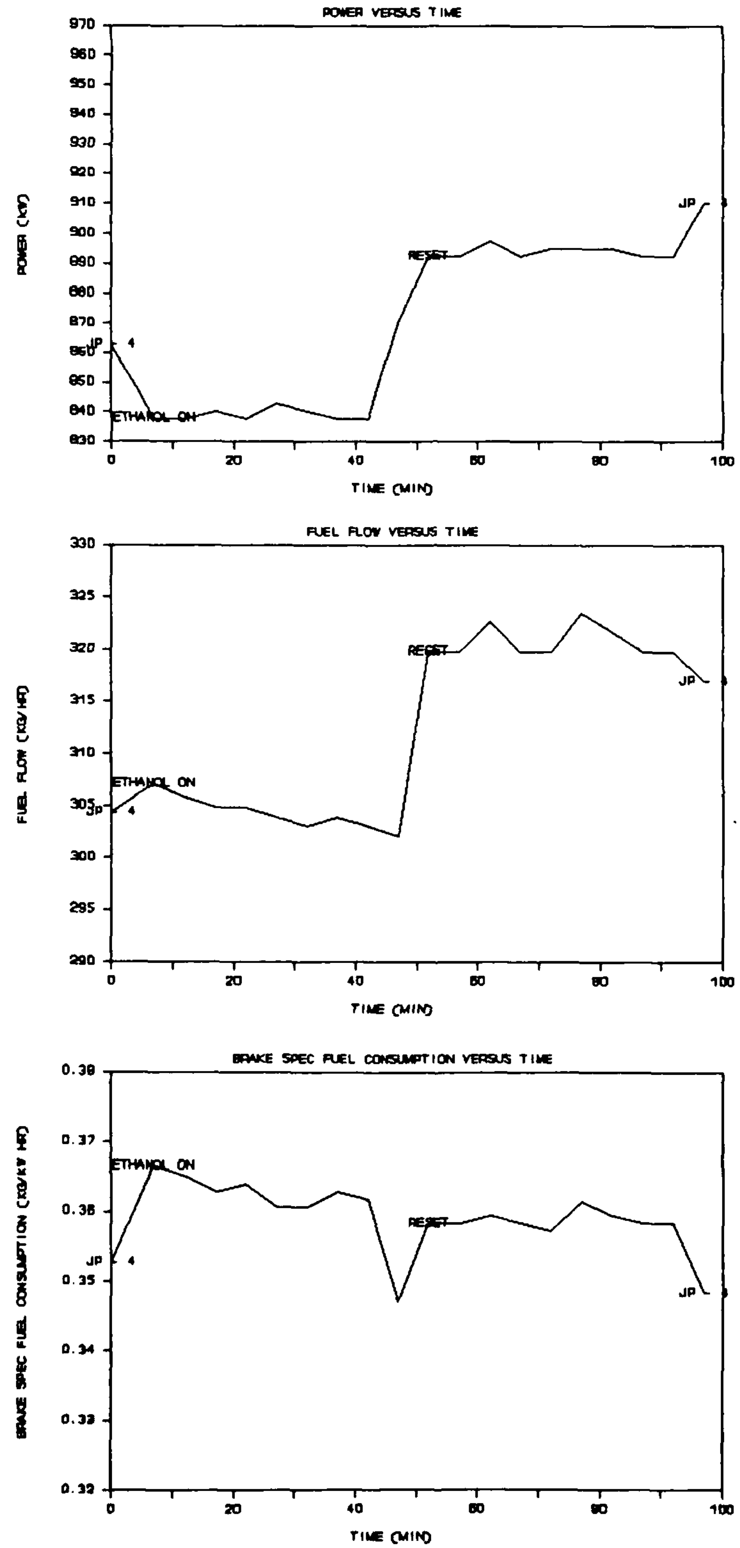


FIGURE A-7. EFFECTS OF 10 PERCENT ETHANOL DURING AN 18,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM RANGE POWER

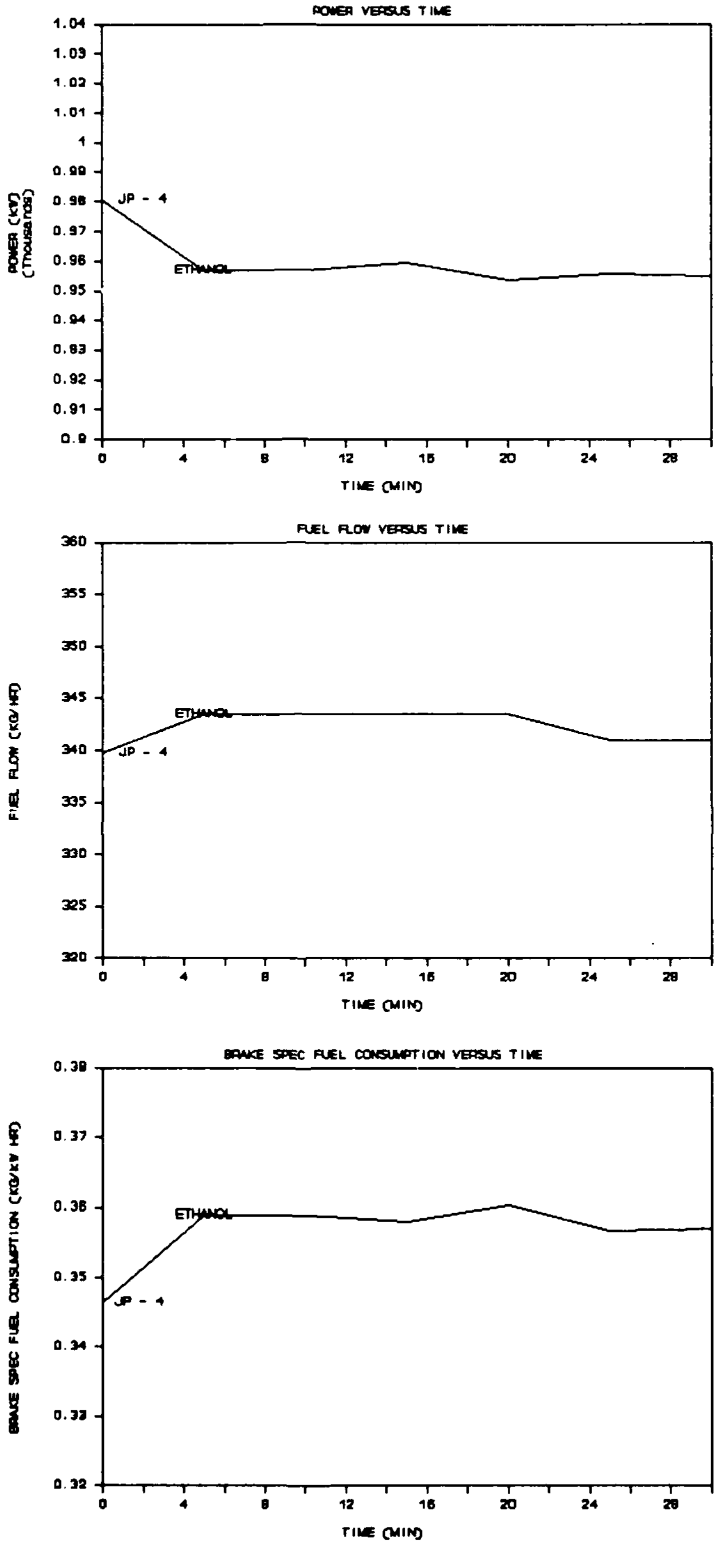
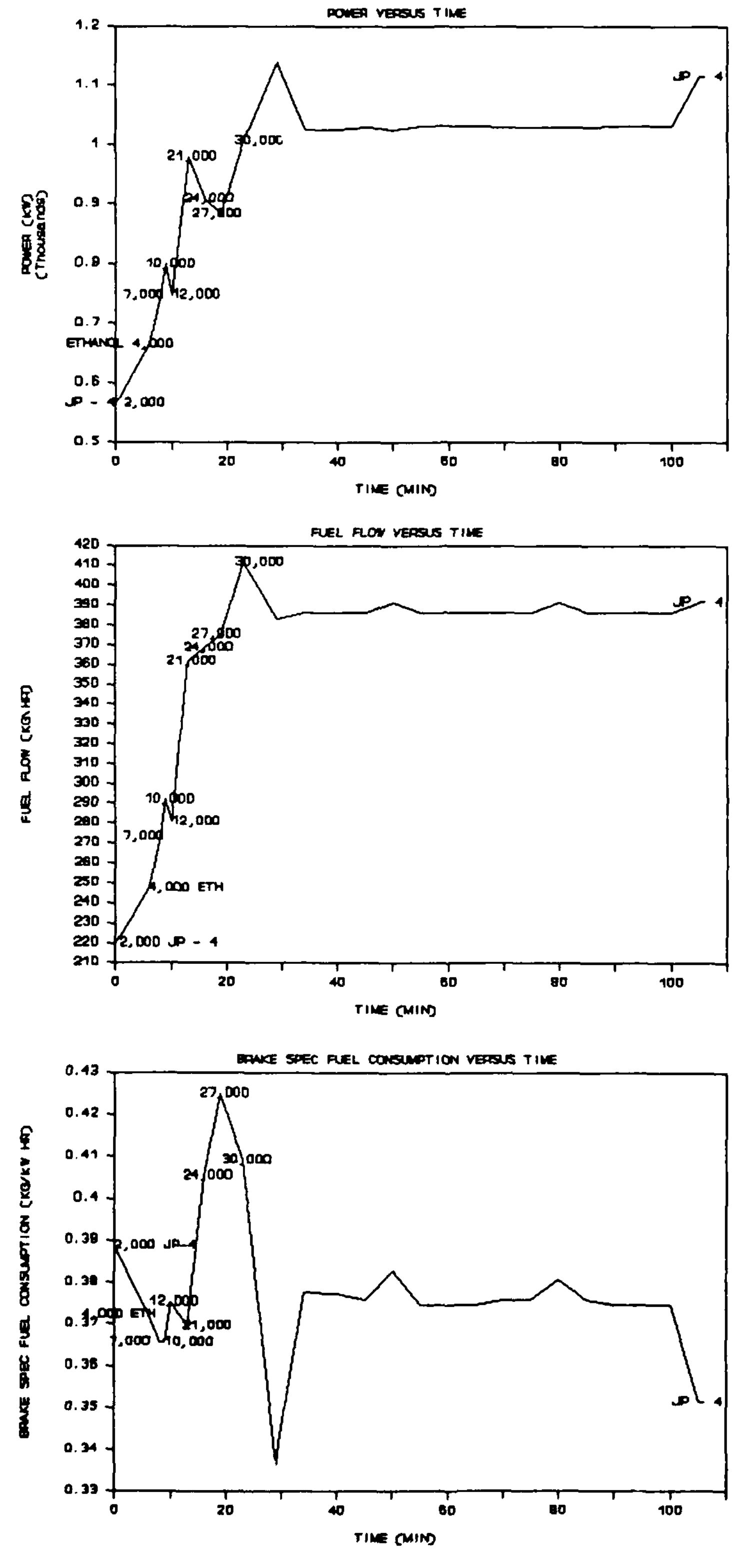


FIGURE A-8. EFFECTS OF 10 PERCENT ETHANOL DURING A 24,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM CONTINUOUS POWER



*U.S. GOVERNMENT PRINTING OFFICE: 1990-704-061/20003

FIGURE A-9. EFFECTS OF 10 PERCENT ETHANOL DURING A 30,000-FOOT ALTITUDE ENDURANCE RUN AT MAXIMUM RANGE POWER